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POINT-OF-VIEW

The California Phenology Project: Tracking Plant Responses to Climate Change

The passing of the seasons is one of the most familiar phenomena on Earth. In California, the appearance of spring wildflowers, farm-fresh produce, and migratory birds and butterflies are welcomed signs of the seasons. Other seasonal hallmarks, however, pose threats to human health and livelihoods, including allergens, crop and vineyard pests, and the high fuel loads that promote wildfires. For better or worse, our health, economies, and resource management practices are intimately connected with seasonal cycles of plants and animals.

The field of science dedicated to studying seasonal biological activities and their responses to environmental variation is phenology. For plants, phenological events and phases (phenophases) comprise every transition in their life cycles, including bud-break, leaf expansion, leaf senescence, flowering, pollen dispersal, the ripening of fruits, and seed dispersal. Long-term observational studies have revealed that for many species the timing and intensity of these phases is sensitive to temperature, precipitation, and/or snowmelt dynamics. This timing inevitably determines an individual's or population's exposure to herbivores, pollinators, seed predators, and fruit dispersers, whose own timing is also sensitive to local environmental conditions. As a result, the timing of seasonal phases—as well as their overlap among interacting species and their responses to climate change—can have strong fitness consequences for individuals, populations, species, and communities, ultimately affecting the diversity and abundance of resources provided by co-occurring plant species. These links between phenology, climate, and climate change are so well known that changes in the phenology of plant and animal species and communities have been identified as a "fingerprint" and key "indicators" of climate change (Parmesan and Yohe 2003; IPCC 2007; EPA 2010).

Recognizing the potential for phenology to provide a rigorous and integrative framework for engaging a wide variety of stakeholders in environmental issues, a consortium of scientists, resource managers, educators, and policy makers have established a continental-scale research, monitoring, and education program focused on phenology. The USA National Phenology Network (USA-NPN), launched in 2007 and operating with major support from the U.S. Geological Survey (USGS), is a collaboration among government agencies, the academic community, non-governmental organizations, and the general public. The USA-NPN harnesses the power of volunteers, researchers, and the internet to collect, to share, and to distribute standardized phenological data through its online observation program, *Nature's Notebook*. These publicly-available data provide baseline information to which future data can be compared, and are currently used to support a variety of contemporary research, education, and management activities.

Leveraging the groundswell of support for the USA-NPN's national framework, the California Phenology Project (CPP) was initiated in 2010 as the first coordinated effort to assess the effects of climate change on California's landscapes (www.usanpn.org/cpp). With funding from the National Park Service Climate Change Response Program (through the Californian Cooperative Ecosystem Studies Unit), the CPP was designed with input from dozens of academic and government scientists and through a collaboration among the National Park Service, the USA-NPN and USGS, and the University of California, Santa Barbara. The primary goals of the CPP are to: 1) recruit, train, and engage scientists, educators, the public, and policy makers in the collection and interpretation of phenological data; 2) detect how phenology is linked to changing climatic conditions over space and time; and 3) collect and analyze data that support stewardship of wildland and managed ecosystems.

The CPP initially formed to develop and test phenological monitoring protocols in California's National Parks in order to inform resource management decisions and to promote climate change interpretation for visitors. A core group of National Park Service resource managers initiated phenological monitoring and education activities in seven pilot parks (www.usanpn.org/cpp/NationalParks; Golden Gate National Recreation Area–Alison Forrestel, Will Elder, and Sue Fritzke; John Muir National Historic Site–Fernando Villalba; Joshua Tree National Park–Josh Hoines; Lassen Volcanic National Park–Janet Coles; Redwood National and State Parks–Stassia Samuels; Santa Monica Mountains National Recreation Area–Christy Brigham; Sequoia and Kings Canyon National Parks–Sylvia Haultain). These efforts provided implementation models and online resources to facilitate monitoring, which are being adapted by additional parks and partners. As a result, the CPP has established a solid foundation of monitoring sites and partnerships throughout the state to support long-term, regionally-coordinated monitoring efforts. The CPP

network has evolved to include the University of California Natural Reserve System (with funding from the UC Office of the President), UC Extension, informal education organizations (e.g., NatureBridge), alternative high school programs (e.g., New Leaf Collaborative), and conservation organizations (e.g., PRBO Conservation Science). The CPP also has offered informational and training sessions at a variety of institutions such as the Desert Institute, botanical gardens, and universities, as well as for members of conservation societies such as the Audubon Society and California Native Plant Society. The CPP is actively seeking organizational and institutional collaborators to lead new and ongoing monitoring efforts. To date, the CPP has:

- developed a scientific framework and research questions to inform long-term and geographically widespread monitoring efforts (www.usanpn.org/cpp/resources);
- led an intensive species selection process, one result of which was the compilation of floras for the University of California Natural Reserve System (Haggerty and Mazer 2011) and California National Parks;
- developed and refined monitoring protocols and resources for 30 widespread, ecologically important plant species in California and coordinated their monitoring across the state;
- conducted >40 half-day to three-day workshops to recruit and train >650 observers, some of whom have delivered subsequent workshops for the staff, volunteers, students, and visitors with whom they engage;
- produced a suite of "phenological literacy" resources with support from USA-NPN and USGS for K–12, college, and public audiences including standards-aligned lesson plans, data analysis activities, guides for phenology gardens and herbarium-based phenology projects, seminar modules, and annotated lectures (www.usanpn.org/cpp/education); and
- contributed >150,000 observation records to the National Phenology Database that is curated by the USA-NPN.

All CPP training, education, outreach, and monitoring resources are available to the public on the CPP website. In addition, documentation of CPP decision-making processes (e.g., scientific framework and species selection) is available on its website so that other regional efforts or national-scale organizations (e.g., National Park Service and National Wildlife Refuge System) can adapt the CPP approach and initiate new networks in coordination with the USA-NPN.

In an effort to increase the value of contemporary phenological data, the CPP also aims to discover and analyze existing historical datasets from which phenological information can be extracted, including unpublished monitoring records; seed collection records; historical photographs repeated at the same location(s) over time; naturalist's journals; and wildflower lists with date and location information. Readers are encouraged to contact the authors with information regarding historical datasets that are available for analysis and digital archiving.

The CPP welcomes new partnerships and opportunities in science, education, and their many applications including resource management and conservation. The interdisciplinary nature of phenological research allows scientists, educators, and students to detect the seasonal rhythms of their local environments using a wide variety of approaches that may be motivated by scientific, cultural, economic, or simply aesthetic interests. With a current network of sites distributed among California's National Parks and UC Natural Reserves, the CPP has developed a foundation upon which graduate students, outdoor educators, classroom instructors, university faculty, and researchers across the biological and physical sciences are invited to build projects and programs. Although the CPP is presently focused on California's flora, the USA-NPN's national framework also includes animal monitoring protocols for terrestrial, coastal, and marine systems, providing potential for the expansion of the CPP scientific framework.

Given that phenological monitoring is easy to conduct and straightforward to teach, the prospective contributions of both professional and citizen scientists to large-scale efforts to track phenological changes are heartening and realistic. The CPP offers an integrative scientific and educational framework for observing and measuring the pace and the timing of the seasons, the onset and duration of which are shifting with the changing climate. Readers are encouraged to explore the California Phenology Project website (www.usanpn.org/cpp) and to contact the authors with queries about getting involved.

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